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ROBOTIC SURGERY IN GYNECOLOGY

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ABSTRACT

Advanced laparoscopic procedures for gynecologic surgery have not been widely adopted in clinical practice despite nearly 20 years of improvements in laparoscopic technology. The da Vinci® robotic surgical system was cleared for use in gynecologic surgery in the U.S in 2005. Many surgeons have embraced da Vinci® technology over conventional laparoscopy because of its technologic advantages of wristed instrumentation, high definition 3-D optics, ergonomics, and autonomy of camera control. Furthermore, many surgeons with limited advanced laparoscopic skills have successfully converted their practice from primarily laparotomy to minimally invasive surgery using the da Vinci® System. The purpose of this article is to review the development of robotic procedures in gynecology through the current literature. This article reviews recent peer-reviewed literature concerning robotic-assisted laparoscopic procedures including hysterectomy, myomectomy, radical hysterectomy, pelvic and aortic lymphadenectomy, trachelectomy, parametrectomy, tubal anastamosis, sacrocolpopexy, and others. The majority of this literature consists of descriptive retrospective case series from the investigator's early experience; in fact these early reports represent innovation of a new operative technique. Some reports compare outcomes to open and standard laparoscopic procedures. Future prospective studies comparing complications, pain, return to routine activity, and long-term clinical outcomes with open and laparoscopic procedures will be necessary to completely appreciate the impact of robotic technology.

Key words: Robotic-assisted laparoscopic surgery; da Vinci® surgery; hysterectomy; endometrial cancer; radical hysterectomy; laparoscopy; minimally invasive surgery; myomectomy; sacrocolpopexy

INTRODUCTION

Robotic surgical technology, and specifically the da Vinci® System (Intuitive Surgical Systems, Inc., Sunnyvale, CA), represents the most significant advancement in minimally invasive surgery (MIS) of this decade. The da Vinci® System was developed by the Stanford Research Institute, the United States (U.S.) Defense Department, and the National Aeronautics and Space Administration in an attempt to allow telesurgery for wounded soldiers. The intent was to position the operating surgeon remote to the battlefield performing surgery through a robotic assistance in the battlefield operating room. While telesurgery was found technically possible, its practical use was limited by several factors including telecommunication band-width requirements. Robotic-assisted laparoscopic surgery (robotic surgery) was further developed by Intuitive Surgical Systems, Inc, commercialized, and was Food and Drug Administration (FDA) cleared in 2001 in the U.S. for urologic procedures, in 2002 for thorascopically-assisted car-

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diotomy, and in 2004 for coronary revasculaization. In robotic surgery, the surgeon is seated in proximity to the patient, viewing the surgical sight in a three-dimensional vision system and controlling wristed laparoscopic instruments through masters and foot pedals while seated at an ergonomically designed control panel. Urologists rapidly adopted the technology in favor of standard laparoscopic and open techniques such that the vast majority of radical prostatectomies performed in the U.S. are now with robotic-assistance.

In April 2005, da Vinci® was FDA-cleared for gynecologic procedures based on preliminary evidence of safety and efficacy from their early experience with myomectomy and hysterectomy at the University of Michigan (1). The standard three and four arm da Vinci® units were soon upgraded with a high definition vision 4-arm "S" system in 2006. Adoption of da Vinci® surgery for gynecology has been rapid as reflected in the fact that PubMed cites three publications in the year 2006, 14 in 2007, and 27 in 2008 using "robotic surgery" and "gynecology" as search words. Furthermore, there are an estimated 825 da Vinci® Systems in use in the U.S. currently and at least 500 gynecologic oncologists have attended at least one robotic training course in the past three years [personal communication, John F. Boggess, M.D.]. Given that hysterectomy represents the second most common operative procedure in the U.S. (650,000), and approximately two-thirds are still performed abdominally through an open incision (2), the impact of da Vinci® on the surgical care of women seeking hysterectomy and other gynecologic procedures is likely to be significant in the coming years.

The purpose of this article is to review robotic applications in general gynecology, gynecologic oncology, reproductive/infertility surgery, and pelvic reconstructive surgery. Current literature with outcomes and comparisons to laparoscopy and laparotomy will be discussed.

THE DA VINCI® TECHNOLOGY

The da Vinci® System has three major components: the vision system, the surgeon console, and the robotic platform. After establishing a pneumo-peritoneum, placing abdominal laparoscopic ports, and "docking" the robot, the surgeon sits at a console and views the pelvis through a three-dimensional, high-definition vision system. The surgeon manipulates cabled EndoWrist® instruments that essentially mimic the freedom of the human hand and wrist. EndoWrist® technology provides better precision of movement and improved visibility, allowing superior operative technique, better exposure, and less torquing of the abdominal wall through the operative ports, which results in less postoperative pain. Furthermore, EndoWrist® technology allows surgical maneuvers that more closely mirror open techniques, allowing those with less advanced laparoscopic skill to progress quickly along the learning curve with difficult tasks such as intracorporeal suturing and knot-tying. The bedside assistant can suction, grasp, retract, and pass suture through an accessory laparoscopic port, as well as manipulate the uterus. The robotic surgeon controls the camera with clutch maneuvers and the master hand controls, and activates energy sources via foot pedals at the console. Robotic surgeons are seated and generally more comfortable than laparoscopic surgeons who stand, often holding two instruments in a somewhat ergonomically contorted fashion, viewing the pelvis on a two-dimensional monitor remote to the patient while communicating camera maneuvers to an assistant. Consequently, fatigue and frustration become less of a limiting factor in the robotic surgeon's day relative to the laparoscopic surgeon.

OPERATING ROOM SET-UP, PATIENT PREPARATIONS, AND TECHNIQUE

Patients at our institution are counseled preoperatively to expect an overnight admission to the hospital following surgery and a less than 10% risk for laparotomy. Mechanical bowel prep with Half Lytely and Bisacodyl Tablets is prescribed to improve visibility in the pelvis and displacement of the bowel for aortic lymphadenectomy. Steep Trendelenberg position with lithotomy requires special consideration to prevent sliding on the operating table. Washable gel-pads are placed under the sacrum and shoulders and a tension strap is positioned over foam eggcrate on the chest. We do not find shoulder stops necessary, and prefer to avoid the risk of shoulder nerve injury associated with their use. Other alternatives include foam eggcrate on the bed and the vacuum bean-bag. Arms are padded and tucked along the torso. For obese patients or patients with cardio-pulmonary disease, we recommend testing ventilatory performance while in steep Trendelenberg position prior to prepping and establishing pneumoperitoneum. Pressure-controlled anesthesia is required for ventilation in steep Trendelenberg and neuromuscular blockade must be maintained throughout the procedure. For particularly high risk patients that may require conversion to laparotomy, we have open instruments available in order to avoid delay should conversion be necessary. Because arms are tucked, we recommend patients undergoing lymphadenectomy have two peripheral I.V.'s placed prior to tucking the arms for safety purposes, although we have had no need for transfusion in our nearly three year, 700 patient experience.

Uterine manipulation greatly expedites hysterectomy and improves safety, far outweighing any unlikely theoretical risk of dislodging cancer cells from the uterus or cervix in our opinion. We prefer the *V-CARE* disposable uterine manipulator (ConMed, Utica, NY) for its ease of placement and single piece design. Many surgeons prefer their experience from laparoscopic hysterectomy using the Zumi manipulator, KOH ring, and a separate pneumo-occluder balloon (Cooper Surgical, Turnbull, CT) (3). Still other surgeons use a metal EEA (US Surgical Corp., Norwalk, CT) rectal sizer as an obturator to distend the vaginal fornices for colpotomy while using the third da Vinci® operating arm for uterine manipulation.

Port sites are anesthetized with 0.5% Marcaine with the camera port placed 19 to 27 cm above the symphysis pubis, depending on the individual patient's height, torso length, uterine size, and need to perform aortic lymphadenectomy. Care must be taken to avoid placing the camera port too close to the uterus or pelvic mass and obscuring view of the anatomy. The daVinci® S model has longer instruments and reach, allowing higher placement of ports than the standard model, which allows easier dissection of aortic nodes and hysterectomy with the same ports. We find placing the third operating arm cephalad to the second arm in the left flank, just above the level of the camera port to allow optimal use as a retractor during aortic node dissection as well as in the deep obturator spaces during pelvic node dissection (Fig. 1).

A zero degree camera lens is used for most cases; however, a 30 degree down lens can provide better visualization of the upper anatomy for peri-renal dissection and omentectomy. We generally operate with mono-polar scissors in the right operative arm, a fenestrated bipolar grasper in the left hand, and a double-fenestrated grasper/retractor in the third operative arm when used. For radical hysterectomy, we place a Maryland's plasma kinetic grasper (Gyrus Medical, Inc., Maple Grove, MN) in the third operative arm to be used as a retractor during lymphadenectomy and as a dissector and energy source during tunneling of the ureter. The Gyrus is preferred for ureteral tunneling because it dissipates less heat laterally than standard bipolar cautery. For all other pedicles, we find bipolar energy through the fenestrated grasper to be most efficient, obviating the need for the patient-side assistant to pass other energy devices. Once the uterus is delivered per vagina, a sterile lap pad inside a glove is used as a vaginal occluder during cuff closure.

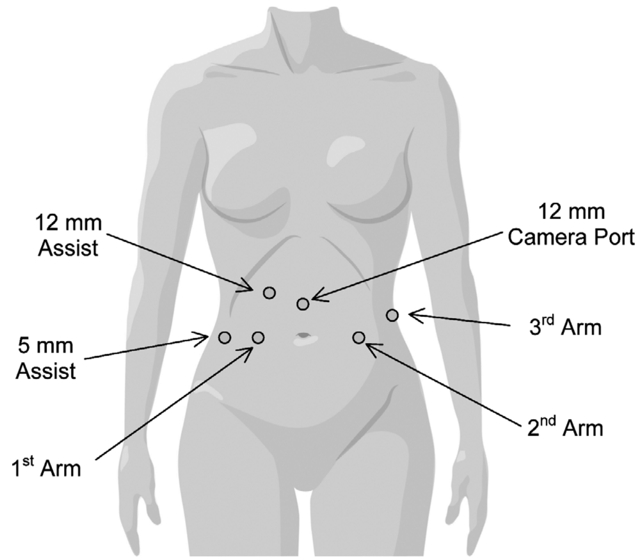

Fig. 1. da Vinci® port set-up for aortic lymphadenectomy.

CURRENT APPLICATIONS IN GYNECOLOGY

ROBOTIC APPLICATIONS IN GENERAL GYNECOLOGY

Performance of hysterectomy is the hallmark of surgical gynecology. Minimally invasive approaches to hysterectomy have been advocated because of quicker recovery with less pain, reduced blood loss, and shorter hospital stay since the 1990's (4). However, complex pathology such as uterine leiomyoma, endometriosis, and chronic tubo-ovarian complexes with adhesions have presented significant challenges for the laparoscopic surgeon. When complex pathology is encountered in the clinic, there is often a decision to avoid a minimally invasive surgery (MIS) approach, or proceed with laparoscopy and liberal conversion to laparotomy, or risk intraoperative injury to adjacent structures with sub-optimal laparoscopic conditions. In fact, laparoscopic hysterectomy has been associated with increased odds for urinary tract injury compared to abdominal hysterectomy (4). The promotion of laparoscopic supracervical hysterectomy is an attempt to modify the standard total hysterectomy in order to simplify the laparoscopic approach and avoid urinary injury, without any other documented patient benefit.

Robotic-assisted laparoscopic hysterectomy has been evaluated by several authors, initially in small pilot series and more recently in a retrospective comparison to total laparoscopic hysterectomy (Table 1). Beste et al (5) was the first to report a small 11 case-series of total robotic-assisted laparoscopic hysterectomy including cuff closure, in 2005. One conversion to laparotomy and one cystotomy were reported; operative times ranged from 148 to 227 minutes. Fiorentino et al (6) next published 20 robotic cases with 2 conversions and one cuff bleeding complication. Reynolds and Advincula (1) published a report of 16 total and supracervical hysterectomy cases with a mean 242 min operative time, complicated by a pneumonia, bowel/bladder injury, cuff hematoma, and wound cellulitis, but no conversions. Recognize these authors initiated the hysterectomy procedures before da Vinci® was well-described or FDA-cleared for gynecologic procedures.

By 2007, reports of larger case series (7–9) appeared with significantly lower operative times, complications, and larger uterine weights (Table 1). Kho et al (7) described specific procedural techniques for operative efficiency in order that operative time could be reduced to that comparable to laparoscopic hysterectomy. Payne and Dauterive (8) published the only comparative study of robotic and laparoscopic hysterectomy for benign disease. This retrospective study compared 100 laparoscopic cases done before the introduction of robotics at the Oschner Clinic with the first 100 robotic hysterectomies. They reported similar uterine weights, operative times, and blood loss, but a significantly higher conversion rate with standard laparoscopy. Additionally, they noted that the last 25 robotic cases had a significantly lower operative time than the laparoscopy cohort (79 *vs.* 92 min) and concluded that robotic hysterectomy was quicker and with less risk for abdominal conversion

TABLE 1

Comparison of surgical experiences from recently published reports of benign cases (robotic-assisted and/or total laparoscopic hysterectomies) for gynecologic surgery.

Factors	Beste et al (5); RALH	Fiorentino et al (6); RALH	Reynolds & Advincula (1); RALH	Kho et al (7), RALH	Payne & Dauterive (8)		Lenihan et al (9); RALH
					RALH	TLH	
Patients (n)	11	20	16	91	100	100	113*
BMI (Kg/m²)	26.0	ND	27.8	27.9 ± 12.1	28.8 ± 6.6	28.8 ± 6.2	29.0 ± 6.1
Uterine weight (g)	49–227 (range)	98 ± 28	132	136 ± 67	267 ± 375	216 ± 173	184 ± 137
Op time (min)	192	200 ± 52	242	128 ± 35	119 ± 59	92 ± 29	107 ± 32
EBL (ml)	25–350 (range)	81 ± 50	96	79 ± 44	61 ± 61	113 ± 86	103 ± 60
Conversion rate (%)	9.1	10.0	0	0	4.0	9.0	1.8
LOS (days)	1.0	2.0 ± 0.73	1.5	1.35 ± 0.69	1.1 ± 0.7	1.6 ± 1.4	1.0
Complications** rate (%)	0	5.0	25.0	6.6	2.0	2.0	3.5

Abbreviations:
RALH = robotic-assisted laparoscopic hysterectomy; TLH = total laparoscopic hysterectomy; EBL = estimated blood loss; BMI = body mass index; Op = operative; LOS = length of stay; min = minutes; ml = milliliter; ND = not determined (or not described).
* Includes 13 non-hysterectomy cases.
** Refers to post-operative complications up to 6-weeks.

than standard laparoscopy. Lenihan et al (9) described a two-surgeon private practice experience recently with robotic-assisted gynecologic procedures and noted operative times stabilized at 95 min after 50 cases for hysterectomy, and this was independent of uterine weight.

ROBOTIC APPLICATIONS IN GYNECOLOGIC ONCOLOGY

Endometrial cancer and robotic surgery

Uterine malignancies are the most common gynecologic cancer in the U.S (40,100 cases in 2008), with the majority of cases being endometrial cancer (10). The standard treatment in most centers is hysterectomy and bilateral salpingo-oophorectomy, along with pelvic and aortic lymphadenectomy for the majority of cases when technically possible. The risk for lymph node metastasis is related to tumor grade, depth of invasion, tumor size, and lympho-vascular space invasion. The International Federation of Gynecology and Obstetrics (FIGO) staging requires lymphadenectomy for assignment of stage, and morbid obesity is usually cited as the most common limiting factor for completing a satisfactory lymphadenectomy. Lymph node status is pivotal in the determination of adjuvant therapy for endometrial cancer, in addition to tumor grade, depth of invasion, and histology of the primary tumor.

Despite the fact that laparoscopic-assisted hysterectomy with pelvic and aortic lymphadenectomy has been championed since Childers' and Surwit's initial report in 1992 (11), only 7.7% of 12,743 patients undergoing surgery for endometrial cancer in California were laparoscopically managed from 1997 to 2001 (12). Furthermore, surveyed members of the Society of Gynecologic Oncologists (SGO) reported that only 49% of U.S. gynecologic oncologists used the laparoscope to stage endometrial cancer, and less than 8% performed laparoscopic surgery in greater than 50% of their cases (13). The multi-center Gynecologic Oncology Group (GOG) Lap-2 trial with 1,696 laparoscopic cases reported a 23% conversion rate and a mean operative time of 3.3 h, indicating difficulty with a significant proportion of cases (14). Reasons for not adopting laparoscopic surgery often cited by surgeons are: prolonged operating times, surgeon fatigue, a difficult and prolonged learning curve, and lack of formal training in advanced laparoscopic technique.

Robotic-assisted laparoscopic hysterectomy with staging lymphadenectomy for treatment of endometrial cancer has quickly replaced conventional laparoscopic and open techniques in many U.S. institutions in a relatively short time since its introduction in 2005. Five-hundred sixty robotic cases were completed on the gynecologic oncology service at Florida Hospital Cancer Institute in 2 ½ years (Fig. 2). Figures 3 and 4 reflect growth of robotic cases on the service and the growth in robotic hysterectomy with lymphadenectomy for uterine cancer respectively. Approximately 60% of endometrial cases are completed robotically and length of stay has reduced from 3.2 for laparotomy to 1.0 day for robotic cases, resulting in a significant improvement in "put-through" for the hospital, freeing up needed inpatient beds (15).

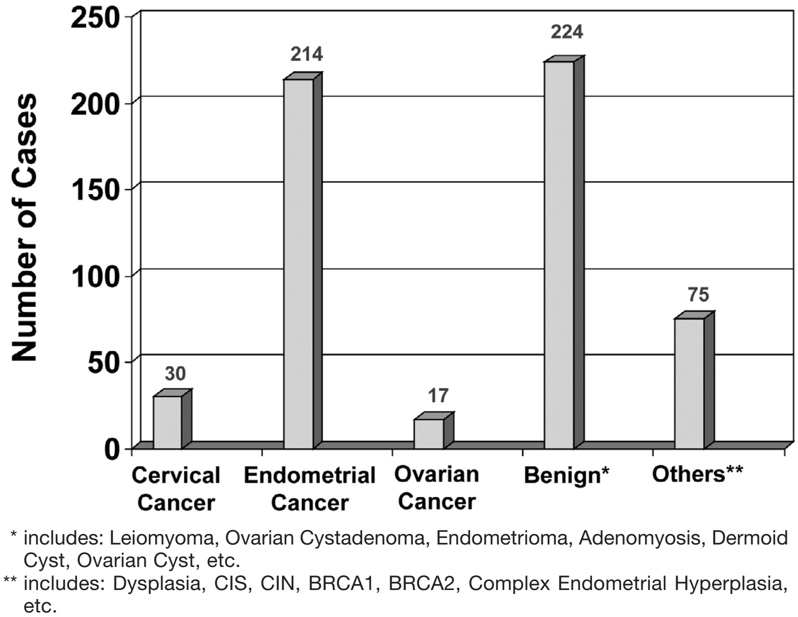

Fig. 2. Robotic cases performed at Florida Hospital Cancer Institute (from May 2006 – December 2008), Total = 560.

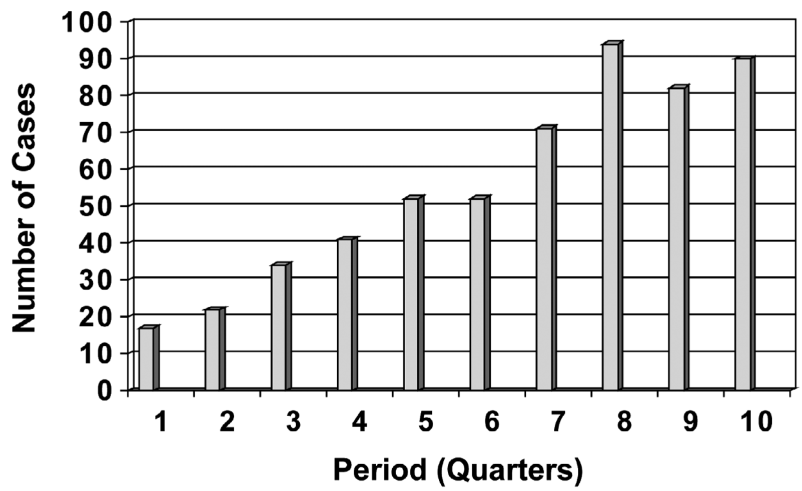

Fig. 3. Quarterly growth in all the robotic-assisted gynecologic cases performed at Florida Hospital Cancer Institute (from May 2006 – December 2008), Total = 560.

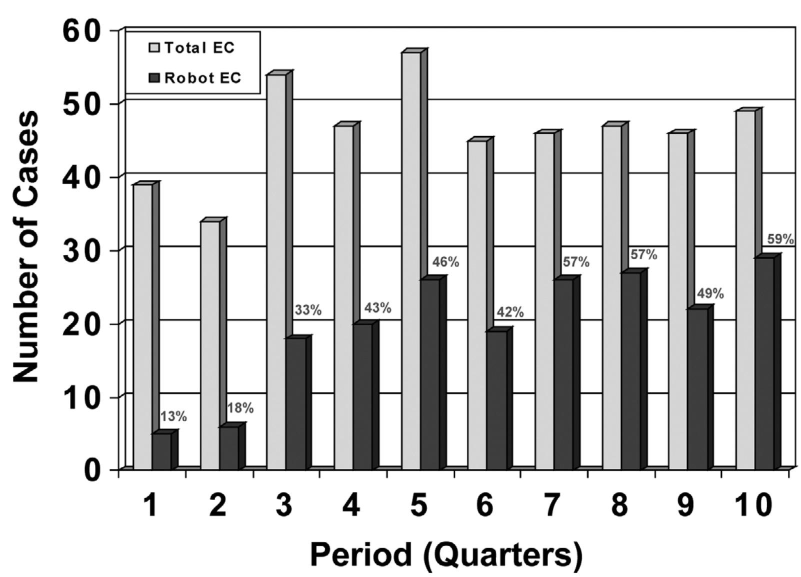

Fig. 4. Quarterly growth in robotic-assisted laparoscopic hysterectomy with lymphadenectomy for endometrial cancer cases at Florida Hospital Cancer Institute (from July 2006 – December 2008).

Table 2 compares five recent publications comparing robotic hysterectomy to laparoscopic and/or open hysterectomy, all reporting favorable results with the exception of longer operating times than open cases and similar operative times to laparoscopic cases (15–19). Reported mean operative times range from 79 to 147 minutes for open cases, 177 to 283 min for robotic cases, and 171 to 287 minutes for laparoscopic cases. Lymph node yields are comparable, and complication rates generally are lower for robotic cases than either open or laparoscopic cases.

Port placement for aortic lymph node dissection has been described by Boggess et al (16) with a supraumbilical camera port, 23 to 25 cm above the symphysis pubis, and an assist 12 mm port in the left upper quadrant. The da Vinci® arms are 10 cm lateral and slightly caudal to the camera port. The third operative arm is placed caudal to the left arm in a gentle arc near the common iliac vessels. Dr. Boggess teaches approaching the right aortic nodes from left to right over the aorta onto the vena cava with scissors in the left hand and graspers in the right. Figure 1 shows our preferred approach at Florida Hospital. The 12 mm assist port is in the right upper quadrant and a 5 mm assist port is in the right flank, whereas the da Vinci® third arm is in the left flank at or just slightly above the level of the camera port, 9 to 10 cm from the left operative arm. We find the ability to retract and expose with the third arm using a double fenestrated grasper preferable in the aortic dissection, with less collision against the left arm, and the "S" instruments are of sufficient length to still reach the pelvis. We rotate the camera 90 degrees such that the surgeon is oriented right to left on the vena cava and aorta with scissors in the right hand and graspers in the left. Our camera port may be placed as high as 27 cm in tall patients. A mini-lap pad is introduced via the 12 mm port and useful for blotting and immobilizing bowel in the left upper quadrant. A U.S. Surgical articulating fan retractor is occasionally useful for displacing small bowel during aortic dissection for short, obese patients with fatty mesenteries. A third approach described by Dr. Magrina et al (20) places the endoscope through the umbilicus with operative ports in the upper abdomen. The table is rotated 180 degrees with the robotic platform at the patient's head (20). This technique might be quite useful for upper aortic dissection particularly with the standard model da Vinci®; that is limited with shorter arms and instrumentation than the "S" model. In order to complete the pelvic dissection, the table must be repositioned with the robot between the legs and new ports inserted.

Obesity is often associated with endometrial cancer, and is usually the "limiting factor" on patient selection for MIS procedures due to difficulty with ventilation in steep Trendelenberg position and maintenance of exposure during aortic dissection. This is especially true where exposure may be compromised by a short, fatty mesentery of the small bowel that compromises small bowel displacement. Right upper quadrant adhesions after cholecystectomy may also limit displacement of omentum and transverse colon, and should be lysed prior to docking the patient cart

TABLE 2

Comparison of surgical experience from recently published reports of robotic vs. open vs. laparoscopic hysterectomy in patients with endometrial cancer.

Parameters	DeNardis et al (15)		Boggess et al (16)			Bell et al (17)			Veljovich et al (18)			Seamon et al (19)	
Surgery	*Robot*	*Open*	*Robot*	*Open*	*Laparoscopic*	*Robot*	*Open*	*Laparoscopic*	*Robot*	*Open*	*Laparoscopic*	*Robot*	*Laparoscopic*
Patients (n)	56	106	103	138	81	40	40	30	25	131	4	85	76
BMI (Kg/m^2)	28.5 ± 6.5	34.0 ± 9.3	32.9 ± 7.6	34.7 ± 9.2	29.0 ± 6.5	33.0 ± 8.5	31.8 ± 7.7	31.9 ± 9.8	27.6	32.2	24.6	34.0	29.0
Op time (min)	177 ± 55	79 ± 17	191 ± 36	147 ± 49	213 ± 35	184 ± 41	109 ± 41	171 ± 36	283	139	255	242 ± 50	287
EBL (ml)	105 ± 77	241 ± 115	75 ± 101	266 ± 185	146 ± 106	166 ± 226	317 ± 282	253 ± 428	67	198	75	99 ± 83	250
Transfusion rates (%)	0	8.5	1.0	1.5	2.5	5.0	15.0	10.0	ND	ND	ND	3.5	ND
LOS (days)	1.0 ± 0.5	3.2 ± 1.2	1.0 ± 0.2	4.4 ± 2.0	1.2 ± 0.5	2.3	4.0	2.0	1.68	5.3	1.2	1.0	2.0
Lymph nodes	18.6 ± 12.4	18.0 ± 9.6	32.9 ± 26.2	14.9 ± 11.3	23.1 ± 11.4	17.0 ± 7.8	14.9 ± 4.8	17.1 ± 7.1	17.5	13.1	20.3	29	22
Complications* rate (%)	3.6	20.8	5.8	29.7	13.6	7.5	27.5	20.0	8.0	20.6	ND	13	14

Abbreviations:
ND = not determined (or not described); EBL = estimated blood loss; BMI = body mass index; Op = operative; LOS = length of stay; min = minutes; ml = milliliter.
* Refers to post-operative complications up to 6-weeks.

TABLE 3

Comparison of surgical experiences from recently published reports of robotic-assisted radical hysterectomy in patients with cervical cancer.

Parameters	Sert & Abeler (30)		Magrina et al (31)			Fanning et al (32)	Ko et al (33)		Kim et al (34)	Boggess et al (35)		Nezhat et al (36)		Lowe et al (37)
Surgery	*Robot*	*Laparoscopy*	*Robot*	*Laparoscopic*	*Open*	*Robot*	*Robot*	*Open*	*Robot*	*Robot*	*Open*	*Robot*	*Laparoscopic*	*Robot*
Patients (n)	7	7	27	31	35	20	16	32	10	51	49	13	30	42
BMI (Kg/m²)	24.6	22.5	27.2	26.8	27.3	ND	27.6	26.6	23.6	28.6	26.1	ND	ND	25.1
Op time (min)	241	300	190	220	167	390	270	203	207	211	248	323	318	215
EBL (ml)	71	160	131	208	444	300	82	666	355	97	417	157	200	50
Transfusion rates (%)	ND	ND	3.7	0	8.6	18	6.3	31.2	0	0	4.0	ND	ND	0
LOS (days)	4.0	8.0	1.7	2.4	3.6	1.0	1.7	4.9	7.9	1.0	3.2	2.7	3.8	1.0
Lymph nodes (Mean)	13.0	15.0	25.9	25.9	27.7	18	15.6	17.1	27.6 (Pelvic)	33.8	23.3	24.7 (Pelvic)	31.0 (Pelvic)	25.0
Complications* rate (%)	42.9	57.1	7.4	9.7	14.3	10.0	18.8	21.9	10	7.8	16.3	30.8	20.0	12.0

Abbreviations:
ND = not determined (or not described); EBL = estimated blood loss; BMI = body mass index; Op = operative; LOS = length of stay; min = minutes; ml = milliliter.
* Refers to postoperative complications up to 6-weeks.

if possible. Gehrig et al (21) reported that robotic surgery was preferable to laparoscopy for treatment of endometrial cancer in obese patients because of shorter operative times, blood loss, hospital stay, and increased lymph node retrieval. Ninety-two percent of the robotic cases and 84% of the laparoscopic cases completed both a pelvic and aortic node dissection. While the lymph node counts were reported greater for robotic than laparoscopic cases, node counts for morbidly obese [body mass index (BMI) > 40 kg/m²] patients were not greater than laparoscopy, indicating that robotic aortic lymphadenectomy may still have some limitations for this group of difficult patients. Seamon et al (19) reported that of 105 patients with endometrial cancer at The Ohio State University, 13 (12.4%) with BMI's ranging from 47 to 58 kg/m² and grade 1 cancer had complete lymphadenectomy omitted; six of these underwent pelvic lymphadenectomy successfully without aortic dissection. There were also 12.4% conversions to laparotomy. The mean conversion BMI was 40 ± 7 kg/m² compared to 34 ± 9 kg/m² for those completed robotically. The feasibility for completing robotic aortic lymphadenectomy was 67% and 35% for BMI 45 and 50 kg/m², respectively. In our anecdotal experience, short stature and the "apple" shape body habitus rather than "pear" shape predicts difficulty with aortic dissection, somewhat independent of BMI.

Lastly, the gynecologic oncologist is often asked to consult for women who were diagnosed with uterine malignancy after a simple hysterectomy has been performed. Depending on the primary uterine pathology, a staging lymphadenectomy and complete removal of the broad ligaments and adnexae are desirable. Standard laparoscopic staging has been useful with less morbidity than laparotomy in this setting (22), and may allow less delay in initiating adjuvant therapy. Laparoscopic re-staging was successful in 80% of patients in a GOG study (23). While this issue has not been addressed in the literature with robotics, our own personal experience with 15 re-staging cases has been uniformly successful, without conversion to laparotomy.

Cervical cancer and robotic surgery

Radical hysterectomy with pelvic lymphadenectomy is the standard operative treatment for stage IA-2 and IB cervical cancer, and laparoscopic radical hysterectomy has been reported by numerous authors to have similar oncologic outcomes as open approaches (24–26). Yet, widespread adoption of this technique in the U.S. has been hampered by the documented excessive operative times and complications associated with laparoscopic radical hysterectomy, in addition to the perceived long learning curve for this technically challenging procedure (27, 28). These barriers led many gynecologic oncologists to investigate use of the daVinci® platform with its "enabling technologies" as viable solution to minimally invasive radical hysterectomy.

Sert is credited with the first published report of a robotic-assisted radical hysterectomy in 2006 (29).

Sert and Abeler (30) then reported a small cohort of robotic and laparoroscopic cases with no statistical differences in operative time, lymph nodes, and parametrial widths; however, blood loss and hospital stays were less. It is noteworthy that despite these being the first cases done robotically, mean operative times were an hour less than their standard laparoscopic approach (30). Table 3 compares published literature of robotic radical hysterectomy (30–37). With the exception of Nezhat et al (36) and Fanning et al (32), the operative times are less than Sert's original pilot experience (30), probably reflecting the initial learning phase in these two small pilot series. In addition, with the exception of two pilot series (30, 36), all other investigators reported fewer complications with robotic assistance. The two larger series from Boggess et al (35) and the multi-site series from Lowe et al (37), both of which also reflect their learning curve experience, show that operative times were approximately 3 h, blood loss was minimal, there were no transfusions, length of stay was one day, and total complications were less than that usually associated with either open or laparoscopic approaches. The Lowe et al (37) report is particularly instructive of the rapid learning curve for robotic radical hysterectomy and the reproducibility of the procedure. They report 42 robotic radical hysterectomy cases from a five-surgeon consortium, clearly accrued during each individual surgeon's early learning curve. Operative times, blood loss, lymph node yields, and complications are strikingly similar to the much larger individual experiences of Drs. Boggess and Magrina.

Radical parametrectomy with lymphadenectomy has been advised as an alternative to pelvic radiation for women with undiagnosed cervical cancer who underwent a simple hysterectomy. This procedure has traditionally been performed abdominally, but has also been described totally laparoscopically (38). A small five-case robotic robotic radical parametrectomy experience was recently reported from M.D. Anderson, Houston (39). The median operative time was 365 min (range 331 to 430 min), EBL 100 ml, median lymph nodes 14, and there were no laparotomy conversions. One intraoperative cystomy was robotically repaired, and there were two postoperative complications: a vesicovaginal fistula and a lymphocele.

Fertility sparing radical trachelectomy with pelvic lymphadenectomy is now considered a safe alternative for women with small lesions who desire maintenance of fertility (40). Robotic radical trachelectomy was first reported by Persson et al (41) with 2 cases in nulliparous women with Stage IB1 lesions. Operative times were prolonged at 387 and 358 min, reportedly due to the "experience factor" with the procedure and frozen section analysis wait times. Geisler et al (42) recently added to the description with a case-report of a IB1 lesion with 172 min operative time and 100 ml blood loss. A featured video of robotic radical trachelectomy was presented during the plenary session of the most recent 40th Annual Meeting of the SGO (43).

ROBOTIC APPLICATIONS IN REPRODUCTIVE ENDOCRINOLOGY

Tubal anastamosis

The application of robotics appears well suited for reproductive endocrinology. Although most surgical procedures are performed laparoscopically, those which are more complex are still performed by laparotomy as they involve precision through microsurgery or extensive suturing. The laparoscopic approach, which has been successfully adopted by the minority, has a steep learning curve, obviating its universal application for more complex reproductive surgery. In 1998, robotic technology was first investigated as a tool to overcome many of the limitations of laparoscopy for reproductive endocrinology. A study in animal models demonstrated that robotic technology using the Zeus® Surgical System could safely be used in microsurgical anastomosis (44). A pilot study in 1999 used the Zeus system to perform laparoscopic tubal anastomosis (45). The procedure was successfully completed in all patients without complications. The mean operative time to complete bilateral anastomosis was 159 ± 33.8 min and at conclusion of the surgery chromotubation revealed patency in both tubes. A hysterosalpingogram showed pregnancy rates at 6- and 12-month follow-up of 89% and 50%, respectively. Goldberg et al (46) compared tubal anastomosis with conventional laparoscopic and with robotic assistance using the Zeus system. The procedure was performed by placing four 8–0 polygalactin sutures at 3, 6, 9, and 12 o'clock. Robotic-assisted procedures resulted in increased operative time (>2 h) as well as increased EBL (although not clinically significant) without considerable improvement in clinical outcomes.

Degueldre et al (47) utilizing the da Vinci® robotic system reported comparable operating times to that of open microsurgery, and pregnancy was reported in 2/8 patients at 4 months following the surgery. In 2004, a feasibility study (48) in a fellowship training program was carried out at the University of Alabama, comparing open microsurgical technique versus the da Vinci® surgical system in tubal anastamosis in 18 patients seeking sterilization reversal. Robotic-assisted procedures resulted in greatly increased operative times, though length of hospital stay, recovery time, and time to return to independent activities of daily living were significantly shorter as compared to the open microsurgery group. An expense analysis evaluating robotic procedures with open microsurgery reported comparable total cost between the two groups (49). More recently, Rodger et al (50) published a retrospective case-control study of tubal reversal performed through robotic assistance compared to minilaparotomy. Although operative times were lengthened in the cohort undergoing robotic surgery, there was a decreased convalescence compared to the minilaparotomy cohort (50). Further studies comparing conventional laparoscopy and robotic surgery are needed to determine if robotic technology is more beneficial in sterilization reversal by assessing operative time, patient satisfaction, and pregnancy outcome.

Our technique

After induction of general anesthesia, the patient is placed in a modified dorsal lithotomy position in Trendelenburg and mobilization of the uterus is provided with an intrauterine cannula. Peritoneal access is obtained using a 12-mm trocar placed directly through the umbilicus. Two lateral 8 mm da Vinci® ports are placed in the mid-axillary line 2 cm below the level of the umbilicus and separated by a minimum of 8 cm between port sites (Fig. 5). At this point a diagnostic laparoscopy is performed to assess the feasibility of the reanastomosis with lysis of adhesion if necessary. An accessory 10-mm port, placed on the left side between the umbilical and the lateral ports is used for irrigation, introduction, and retrieval of suture material. The robot is then positioned between the patient's legs and the robotic arms are connected to the respective ports.

Once the set up is completed, the distal tubal segment is stripped of its serosa (Fig. 6a) using microscissors and the tip is resected (Fig. 6b). The proximal segment is mobilized and the proximal segment is transected (Fig. 6c, d). Chromopertubation is used to demonstrate patency of the proximal tubal segment (Fig. 6e). The mesosalpinx is reapproximated with one or two interrupted 6–0 polygalactin sutures (Fig. 6f). The mucosal and muscular layers of the tubal segments are suture with four interrupted 7–0 polypropylene sutures (Fig. 6g). The serosa is closed separately with interrupted 7–0 polypropylene suture (Fig. 6h) and the patency demonstrated through chromotubation.

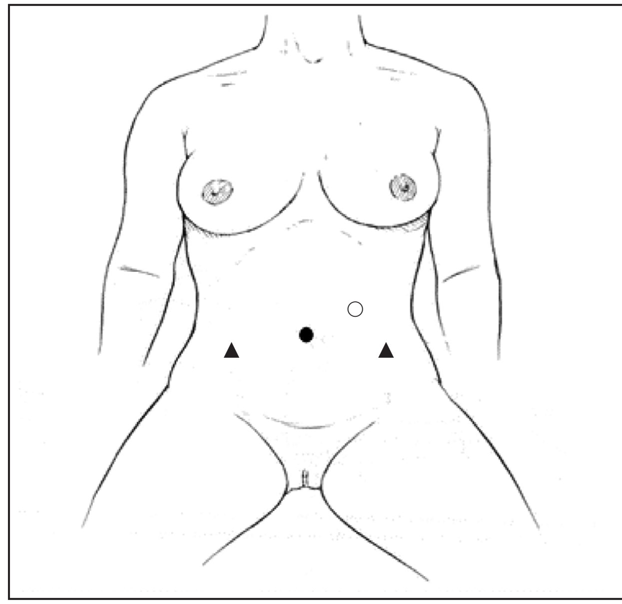

Fig. 5. Trocar placement for robotic tubal reversal.

Myomectomy

Surgical treatment of infertility patients with uterine leiomyoma is controversial, because there is no defined causal relationship between uterine fibroids and infertility, and myomectomy is not without risk (51, 52). Several authors have suggested that the presence of uterine myomata may be associated with infertility and recurrent pregnancy loss (52, 53). Uterine fibroids are thought to interfere with fertility either by interfering with sperm migration and embryo transport, or by causing vascular changes that impede embryo implantation (54). Gianaroli et al (55) evaluated the role of assisted reproductive technology (ART) and pregnancy rates in patients with intramural fibroids. This study advocated myomectomy in patients with inner myometrial fibroids >3 cm in diameter or multiple fibroids. The American Society for Reproductive Medicine advocates surgical management of myomas in patients that desire their fertility only if the myoma causes distortion of the uterine cavity. Furthermore, since surgery is not without risk, patients should be evaluated for other causes of infertility prior to surgery (56).

In 1931, Bonney (57) standardized abdominal myomectomy as the treatment of choice for women wishing to preserve fertility. Semm (58) demonstrated the feasibility of laparoscopic myomectomy (LM) as an alternative to laparotomy in 1979. Some authors suggested that laparoscopic suturing was often difficult and that concern was noted for appropriate closure (45, 59, 60). In light of this, robotic-assisted LM has emerged to attempt to improve intra-abdominal suturing.

One of first series reported in the literature using the da Vinci® robot was used to perform myomectomies in 35 patients (60). The mean diameter of fibroids was 7.9 ± 3 cm, mean weight was 223 ± 244 g, and each patient had an average of 1.6 fibroids removed at the time of surgery. The conversion rate from robotic to laparotomy was 8.6%, comparable to that of conventional LM. The study reported mean EBL to be 169 ± 198 ml with average operative times of 230 ± 83 min. Furthermore, operative times decreased with increased surgical experience (61). A retrospective study evaluated the feasibility of performing robotic-assisted myomectomies in a university setting. Robotic-assisted myomectomy was attempted in 15 patients with conversion to laparotomy in the second patient. Operative time ranged from 159 to 389 min with the average being 249 min. Average blood loss was 160.7 ml. Myomas ranged from 4 to 15 cm in various locations on the uterus. Eighty-seven percent of patients were discharged home by postoperative day 1 and patients returned to work on average 2.8 weeks after surgery (62).

More recently, with increasing levels of experience, comparison trials have been published. Advincula et al (63) published a retrospective case-matched comparison of robotic-assisted laparoscopic myomectomy to myomectomy through laparotomy. The operative time was higher in the robotic cohort; however, compared to the open cohort, robotic myomectomy was associated with less blood loss and shorter hospitalization (63). Nezhat et al (64) confirmed this increase in operative time with robotic surgery in a trial matching laparosopic myomectomy to robotic myomectomy. Matched for age, BMI, parity, previous sur-

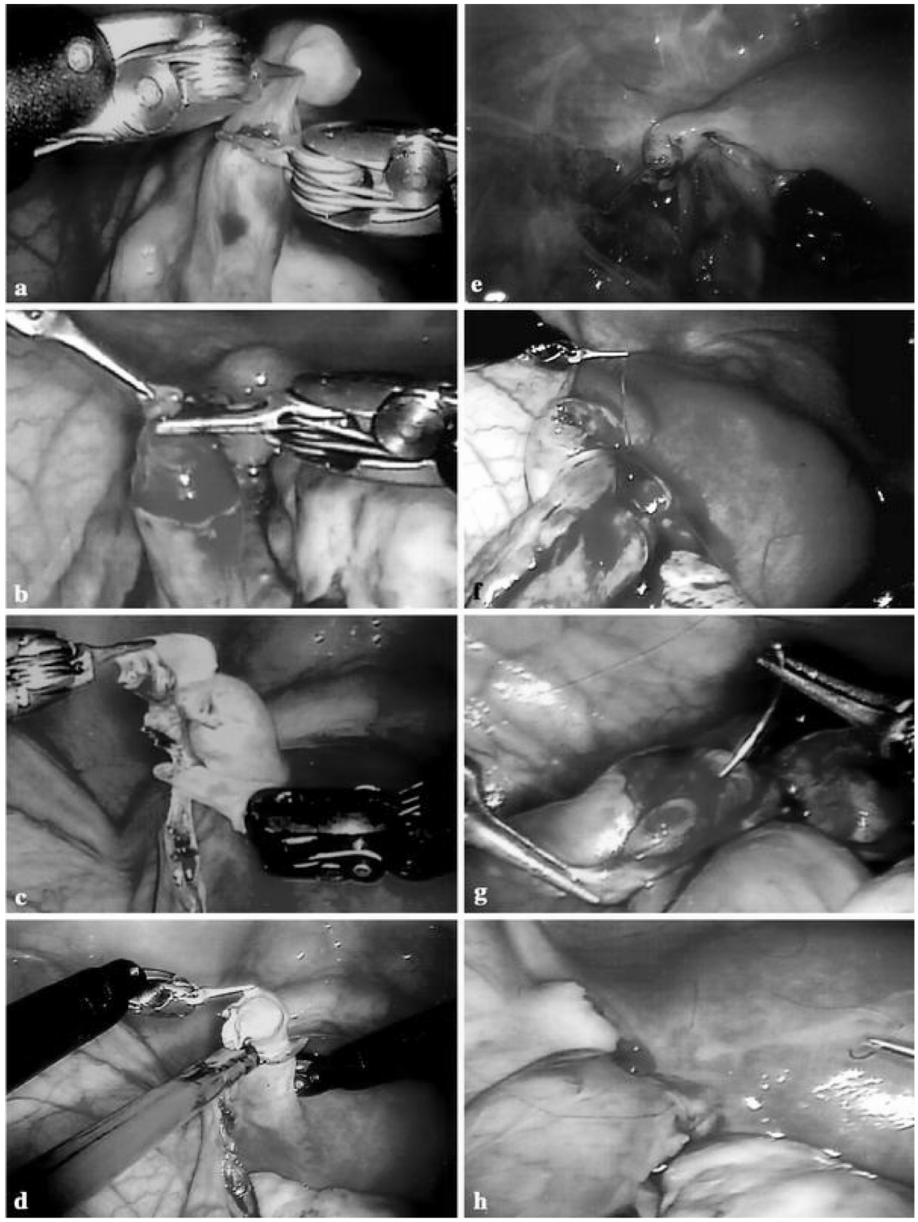

Fig. 6. Robotic tubal reanastomosis procedure. a: Serosal stripping. b: Distal lumen. c: Preparation of the proximal fallopian tube. d: Proximal fallopian tube. e: Chromopertubation. f: Mesosalpingeal suture. g: Six o'clock suture. h: Serosal suture.

gery and fibroids, the only notable difference between both groups was an increase in operative time with robotic myomectomy (64).

Surgical technique

After induction of general anesthesia, the patient is placed in a modified dorsal lithotomy position in Trendelenburg and mobilization of the uterus is provided with an intrauterine cannula. Peritoneal access is obtained using a 12-mm trocar placed 2–5 cm above the umbilicus (10 cm from the top of the uterus). Two lateral 8-mm da Vinci® ports are placed in the mid-axillary line 2 cm below the level of the umbilicus and separated by a minimum of 8 cm between port sites. A fourth da Vinci® port is placed at the level of the anterior superior iliac spine, 8 cm lateral and 2 cm superior to the left lateral port. An accessory port is placed 8 cm lateral to the right lateral port for suture removal, placement, irrigation, and traction (Fig. 7). At this point a diagnostic laparoscopy is performed to assess the feasibility of the myomectomy with lysis of adhesion if necessary. The robot is then positioned between the patient's legs and the robotic arms are connected to the respective ports.

Once the set is completed, Pitressin is injected percutaneously through the umbilicus into the serosa of the uterus (Fig. 8a). Then an incision is made utilizing hook cautery or monopolar scissor through the serosa into the myoma (Fig. 8b). Once the myoma is clearly identified and the pseudocapsule entered, a tenaculum is placed for countertraction. Utilizing the hook and the bipolar cautery dissector the myoma is enucleated careful not to remove the myometrium in dissection (Fig. 8c, d). The fourth arm can house either the prograsp to help with enucleation or tenaculum for traction. Upon complete enucleation, chromotubation is performed to document entry into the cavity. If so, the cavity is repaired with a 3–0 absorbable suture in an interrupted fashion. If not, the muscular layers are repaired in two or three layers in an exact fashion to the open technique (Fig. 8e–g). If the defects are significant, a slip-knot technique can be used to approximate the muscular layers appropriately. Once the repair is completed, a lateral port is converted to accept the morcellator and the fibroid is morcellated (Fig. 8h).

The role of robotic surgery has also been investigated in the pregnant population. In utero, a sheep model demonstrated the feasibility of creation and repair of a full-thickness skin lesion for repair of myelomeningocele using the daVinci® System. Four of the six fetal lambs survived until sacrifice. This study entertains the role of intrauterine endoscopic surgery to reduced associated risks of fetal surgery (65). In addition, there have been reports of robotic-assisted laparoscopic cerclage by two groups. Barmat et al (66) reported on the first robotic-assisted laparoscopic placement of an abdominal cerclage. This was then confirmed in a small series of seven patients by Fechner et al using Mersilene tape (67).

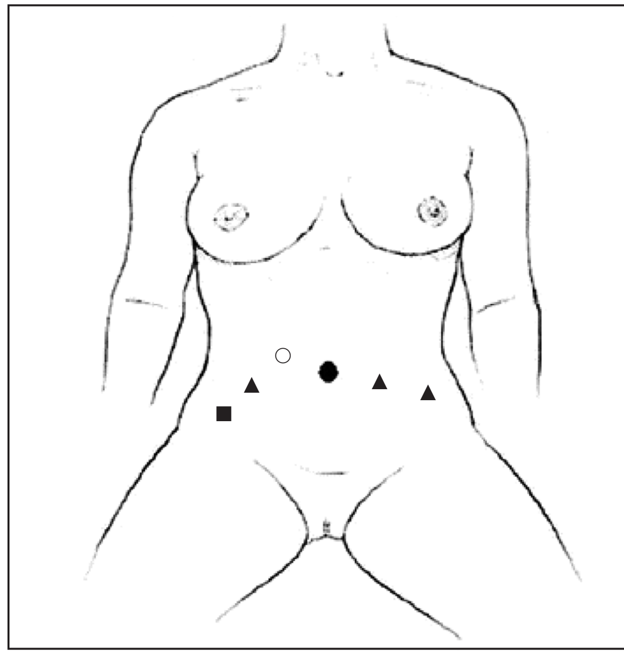

Fig. 7. Trocar placement for robotic myomectomy.

PELVIC RECONSTRUCTIVE SURGERY

Pelvic reconstructive surgery is the most recent subspecialty recognized in obstetrics and gynecology, and the sub-specialty that has quickly assimilated the technology for its most complex procedures.

Sacrocolpopexy seems particularly suited for robotic surgery given the necessity of intracorporeal suturing. The technique involves an initial laparoscopic survey followed by lysis of adhesions if appropriate. The vesicovaginal, rectovaginal, and presacral spaces are then carefully developed using monopolar cautery when necessary for hemostasis. Mesh is then sutured to the anterior and posterior vagina and then to the anterior ligament of the sacrum. Some surgeons use the robotic surgical system for the entire procedure, whereas others use robotic assistance only for suturing. This dichotomy of technique may account in part for the variance in operative times. First described in 2004 by DiMarco et al (68), subsequent series of 31 patients by the same group have shown an operative time on average of 3.1 h with a 24 h hospital stay and complications in four women involving either recurrence of prolapse or vaginal extrusion of the mesh (68-70). In this study, the robotic assistance was for suturing. In a second series by Daneshgari et al (71), 15 patients affirmed the feasibility although they experienced a 20% conversion rate (to either open, vaginal or laparoscopy). The EBL was 81 ml and the mean hospitalization time was 2.4 days (71). A series by Ayav et al (72) evaluated the role of robotics in 12 patients who underwent a colpohysteropexy. The mean operative time was 170 min, with no complications. In this series, the entire case was performed robotically (72). The largest series reported is from Geller et al (73), which is a comparison trial of 73 robotic and 105 open abdominal sacrocolpopexy cases. Patients were comparable for age, BMI, and concomitant surgery. The robotic group has statistically significantly increased operative times (an average of 328 min), but decreased surgical blood loss (average of 103 ml) and length of stay. The patient postoperative prolapse assessment was comparable over most parameters in both groups (73). The purported advantages of the robotic approach include the increased visualization and dexterity specifically as it relates to the dissection of the pre-sacral space, positioning of the mesh and intracorporeal suturing (74).

Another procedure which has found an application for robotic assistance is laparoscopic vesicovaginal repair, which was first described by Melamud et al in 2005 (75). The robotic fistula repair was performed in 280 min with an EBL of 50 ml. The initial excision of the fistulous tract was performed laparoscopically and the daVinci® System was used to repair the vaginal and the bladder in the standard fashion. Sixteen weeks later, the patient remained continent. This initial report was followed by Sundaram et al (76), where a series of five patients underwent a robotic vesicovaginal repair. The entire procedure was performed robotically with an operative time of 233 min and at 6 month postoperative follow-up, all five patients remained continent. Other small series have confirmed the feasibility (77). In addition, robotic-

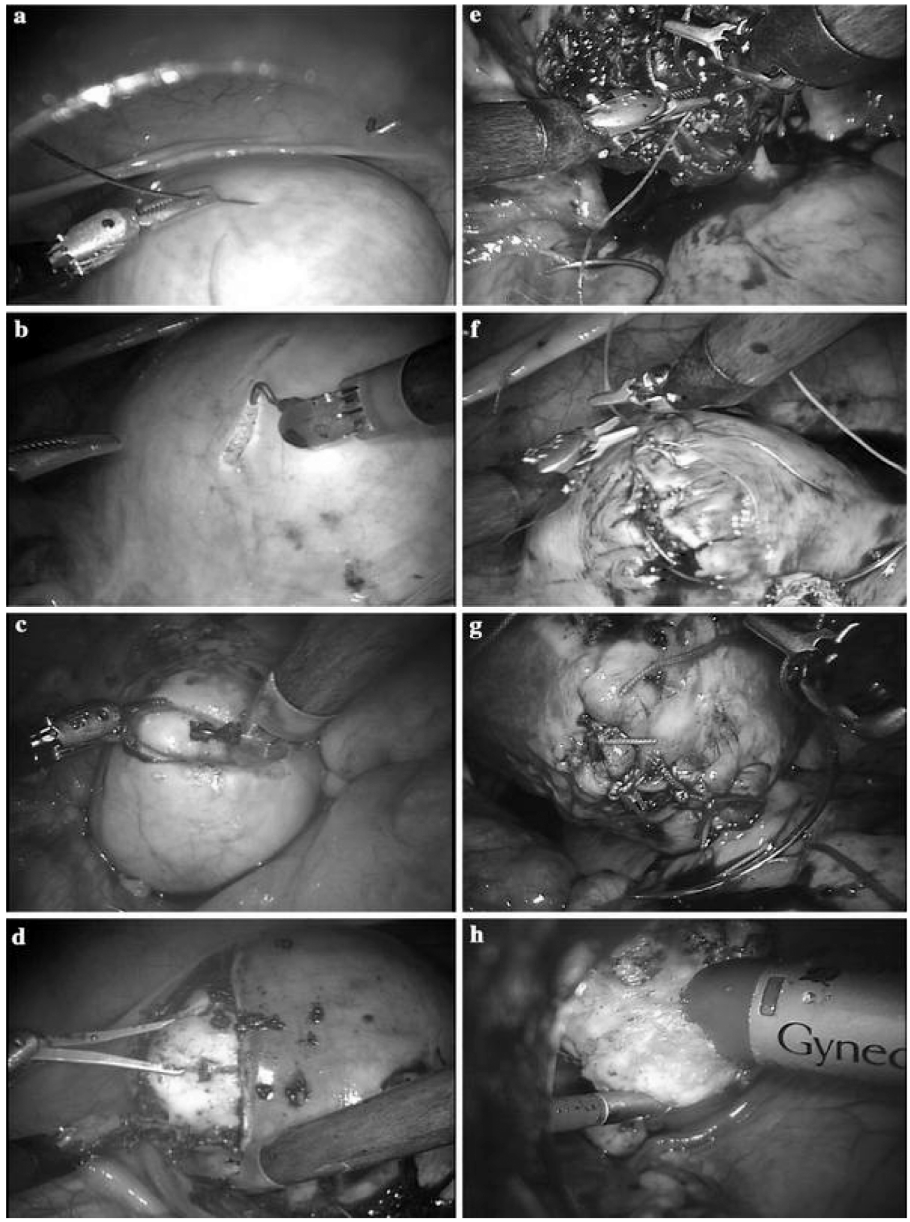

Fig. 8. Robotic myomectomy procedure. a: Injection of Pitressin. b: Serosal incision. c: Dissection and enucleation of myoma. d: Enucleation of myoma. e: Suturing of the myometrium. f: Suturing of the serosa layer. g: Completion of serosal suturing. h: Morcellation.

assisted rectovaginopexy for correction of rectal prolapse was described by Draaisma et al (78). The median operative time was 160 min, median blood loss was <60 ml, and the median hospital stay was 4 days. Two patients had recurrence of prolapse and 87% remained satisfied with their outcomes (78).

Initial studies concerning the role of robotics in pelvic reconstructive surgery are encouraging, and the techniques appear to enhance conventional laparoscopic procedures. Large randomized trials evaluating long-term outcomes are needed to definitively evaluate robotic techniques and outcomes in comparison to laparoscopy and laparotomy.

CONCLUSIONS

Robotic-assisted laparoscopy for use in gynecologic procedures is currently in the developmental and early adoption phase of the technology lifecycle. The da Vinci® Surgical System enables more surgeons to provide patients with a minimally invasive approach by facilitating techniques that more closely mirror open maneuvers, and helping the experienced laparoscopist push beyond the procedural barriers of conventional laparoscopy. The da Vinci® System has thus far had its largest impact in gynecologic oncology; however, many more general gynecologists are likely to train and adopt this technology in the next few years. Currently, literature consists of descriptive surgical technique and retrospective comparisons of case series with clinical outcomes, largely from investigators' early learning experiences. Multi-institutional data and randomized clinical trials comparing da Vinci® robotic surgery, standard laparoscopy and laparotomy will undoubtedly be forthcoming and shed light on both the drawbacks and benefits of robotic-assisted laparoscopic surgery from the perspective of patients, surgeons and institutions.

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